AD NUMBER
AD499910
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; APR 1951. Other requests shall be referred to Office of the Chief of Ordnance, Washington, DC.
AUTHORITY
OCO D/A ltr, 2 Sep 1981

AD 499910

AUTHORITY: OCO D/A Notice, 2 Sep 81

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

UNANNOUNCED

AD499910

AD499910

Technical Report 13

THE CONVENTIONAL AND NOTCHED LONGITUDINAL TENSILE PROPERTIES OF COLD WORKED AISI 4040 AND 8630 STEEL TUBES

WAL Report 310/90-52 Sub Project TB4-121
Contract DA33-019-ORD-7
OFFICE OF CHIEF OF ORDNANCE

1074270

Technical Report No. 13

by

METALS RESEARCH LABORATORY
DEPARTMENT OF METALLURGICAL ENGINEERING
CASE INSTITUTE OF TECHNOLOGY

On a Research Project Authorized

by

Office of Chief of Ordnance
Research and Development Branch
Materials Division ORDTB

INVESTIGATION OF THE SIGNIFICANT PROPERTIES AND CHARACTERISTICS OF COLD WORKED STEELS.

The Conventional and Notched Longitudinal Tensile Properties of Cold Worked AISI 1040 and 8630 Steel Tubes

WAL [redacted] 10.45-S
~~Priority 9A~~

Report No. 310/90-52
April 1951

Contract DA-33-019-ORD-7
Sub Project No. TB4-121

Object

The object of the investigation, the results of which are reported herein, was the determination of the conventional and notched tensile properties of cold drawn AISI 1040 and 8630 steel tubes using longitudinally oriented test pieces cut from the tube walls.

Summary

Cold working tubes of AISI 1040 and 8630 steels by amounts up to 65 per cent (reduction in area) brought about a rise in tensile strength from about 85,000 psi to approximately 125,000 psi with a decrease in ductility (contraction in area) of only 10 per cent (65 to approximately 55 per cent). Moreover, the tubes at this high reduction were not notch sensitive, as measured by the concentric static notch tensile test.

The dependence of tensile strength on amount of cold work was found to be almost linear within the ranges studied, but discontinuous as the mode of cold work changed from drawing (tension) to "rocking" (compression). The dependence of tensile ductility on amount of cold work was again almost linear for drawn tubes (up to 25 per cent reduction). However, tubes rocked to reductions of 51 and 65 per cent showed ductilities which were almost independent of the amount of cold work.

Cold work by drawing appeared to be much more effective in raising the strength and reducing ductility than that by rocking for the same amount of cold reduction.

Thermal stress relieving had little effect on the tensile properties of the drawn tubes (10 and 25 per cent reductions), but the tensile strengths of the rocked tubes (51 and 65% reductions) were slightly lowered and their ductilities were somewhat increased by the thermal stress relieving.

THE CONVENTIONAL AND NOTCHED
LONGITUDINAL TENSILE PROPERTIES OF COLD WORKED
AISI 1040 AND 8630 STEEL TUBES

INTRODUCTION

The overall purpose of the investigation, of which this report constitutes one phase, was one of improving the mechanical properties of steels through the mechanism of cold work rather than by the more commonly used method of heat treatment. Among the advantages of using cold work instead of heat treatment are the savings of strategic alloys as well as heat treating capacity.

Work previously reported on the project has indicated that the hardening and strengthening of steel bars, within certain limitations, appears feasible and practical. However, most of the work has dealt solely with bars. For ordnance (and commercial) purposes, a study of the strengthening effects of cold work on tubes seemed desirable since many components of ordnance items require tubular material. Consequently, a portion of the investigation has been assigned to the study of cold worked tubes.

Among the more basic information necessary for the evaluation of any strengthening effects are the tensile test properties. Perhaps the most commonly used tensile properties are those derived from testing specimens with straight cylindrical test sections. At the same time the suitability of a metal for use under more severe service conditions may be evaluated by the use of a tensile test in the presence of complicated stress states and stress raisers. One test into which has been incorporated both of these latter factors is the static notched tensile test. This test has been used successfully in recent years to differentiate among steels designed for use under adverse service conditions.

This report contains the results of an investigation to determine the effect of cold work on the regular and notched tensile properties of AISI 1040 and 8630 steel tubes. Because of the large size of the tubes and the limitations of testing equipment available, the properties were obtained from test pieces cut from the walls of the tubes*. The specimens were oriented parallel to the axis of the tubes so that the properties may be considered to be those in the longitudinal direction.

* It is hoped that at a later date tensile properties of full section tubes will be available. Such tests are contemplated at Watertown Arsenal on tubes of the same heats as those used for this current study.

MATERIAL

A plain carbon steel, AISI 1040, and a low alloy steel, AISI 8630 were selected for the study. Carbon contents in the range of 0.30 to 0.40 per cent were chosen because earlier studies had indicated that lower amounts of carbon failed to impart to the steels the ability to be work hardened to the desired values. The plain carbon steel represented a material with little strategic alloy content, while the low alloy steel was typical of a material whose rate of hardening with cold work was thought to be enhanced by the small alloy additions.

The steels* were of the following analyses (weight per cent):

AISI Alloy	C	Mn	P	S	Si	Cr	Ni	Mo	EHN Grain Size
E1040 B-W Heat No. 19331	.38	.67	.020	.021	.30	.24	.15	.02	4/5
E8630 B-W Heat No. 28619	.29	.79	.018	.030	.28	.46	.60	.20	6/7
E8630 B-W Heat No. 26763	.31	.84	.014	.023	.27	.51	.47	.20	7/8

All three heats were made in 15 ton basic electric furnaces; each was aluminum killed. A summary of the cold finishing schedules for the steels can be found in Technical Report No. 12, (WAL Report No. 310/90-51).

Hot rolled and normalized tubes were used for the cold finishing. Cold reductions of 10 and 25 per cent for both steel grades were performed on a draw bench with a single pass for each reduction. The tube sizes prior to cold work were 5.45 inch diameter with 0.540 inch wall thickness and 5.625 inch diameter with 0.625 inch wall thickness for the tubes to be

- - - - -

* These steels were standard commercial grades made and drawn under controlled commercial conditions. All heats were made and hot rolled at the Babcock & Wilcox Tube Company, Beaver Falls, Pa. Cold finishing of the tubes with lesser amounts of cold work was accomplished by draw bench methods at the Babcock & Wilcox plant. Cold finishing of the tubes with greater amounts of cold work was performed by the Rockrite process at the Tube Reducing Corporations, Wallington, New Jersey. A complete description of the fabrication of the tubes may be found in report WAL No. 310/120-7, issued by the Babcock & Wilcox Tube Company and dated February 20, 1950.

cold finished with 10 and 25 per cent reductions respectively. Finish sizes for both reductions were 5.255 inch diameter with 0.502 inch wall thickness. Drawing dies had characteristic angles of 12-15°.

Cold reductions of 51 and 65 per cent for both grades of steel were accomplished by the Rockrite process, using a single pass in the former case and two passes with no intermediate anneal in the latter case. The tube size prior to cold finishing was 5.760 inch diameter with a wall thickness of 0.755 inch for tubes to be given both the 51 and 65 per cent reductions. The finish size of tubes rocked to a 51 per cent reduction was 4.503 inch diameter, 0.455 inch wall thickness, while that of tubes rocked to a 65 per cent reduction was 3.750 inch diameter, 0.400 inch wall thickness.

All tubes of the 1040 steel, both drawn and rocked, were from the same heat (B-W Heat No. 19331). Drawn tubes (10 and 25 per cent reductions) of the 8630 steel were from B-W Heat No. 28619, while the rocked tubes (51 and 65 per cent reductions) of this steel were from B-W Heat No. 26763.

The cold drawn tubes were tested in the roller straightened condition, tubes reduced by the "Rockrite" process were tested without the straightening operation.

Tubes of both steels (in all reductions) were tested in two conditions, aged and stress relieved. The aging treatment (arbitrarily established early in this program) consisted of heating for four hours at the temperature of boiling water and air cooling. It was designed to accelerate any aging which might take place over longer periods of time. The stress relieving treatments* are listed below:

Steel AISI 1040 - Heat to 900°F, hold 2 hours, air cool
Steel AISI 8630 - Heat to 1000°F, hold 2 hours, air cool

These treatments were employed to reduce the residual stresses induced by the cold work to a minimum without sacrificing the increase in hardness brought about by the cold work.

- - - - - - - - - - - - - - - - -

* The studies leading to the selection of the thermal stress relief treatments are described in Technical Report No. 12, WAL Report No. 12 310/90-51, dated April 1951.

PROCEDURE

Both conventional tensile and notch tensile tests were made on the steels investigated. Test specimens were machined from blanks cut from the wall of the tubes so that the specimen axis was on the mid-wall thickness and parallel to the tube axis. Because of the limitations of the wall thickness of the tubes, it was not possible to use standard size specimens. The specimens used are shown in Fig. 1. Triplicate specimens were used to establish the tensile properties for each steel condition.

Conventional tensile properties were obtained with specimens of the type shown in Fig. 1. Stress-strain curves were made for each specimen to a point sufficiently far to permit the determination of the yield strength by the 0.2 per cent offset method. Elongations were measured from a gage length which was initially four times the specimen diameter. The tensile strength and contraction in area were measured by conventional means.

Notched tensile properties were determined with specimens of the type shown in Fig. 1. The 60°V notch removed 50 per cent of the cross sectional area. Two root radii; 0.0005 inch and 0.032 inch were used. These specimens, as well as the unnotched specimens, were tested in fixtures specially designed to produce a high degree of concentricity in loading. In the notched tests, the notch strength (defined as the ratio of maximum load to initial area at the base of the notch) and the notch ductility (defined as the per cent decrease in area at the notch base after fracture) were measured.

RESULTS AND DISCUSSION

Conventional Tensile Tests

The results of the conventional tensile tests are shown tabularly in Tables I and II, and are graphically shown in Figs. 2 to 5.

The (conventional) strength properties of both the 1040 and 8630 steel tubes rose rapidly with increasing amounts of cold work, Figs. 2 and 4. For the tensile strength, the rise was almost linear over the entire range of cold reductions tested, while for the yield strength, the increase was more rapid at the lower amounts of cold work. A striking similarity (in regard to these strength properties) can be noted between the two steels. The strengths in the normalized condition were almost

identical, and the reaction to the cold work was about the same for each steel, the maximum strength attained being about 125,000 psi for the highest reduction (aged).

The stress relieving treatment had little effect on the strength properties of either steel with the low (drawn) reductions. However, there was a marked effect at the higher (rocked) reductions. The stress relieving treatment decreased both the tensile and yield strength of all tubes with these higher reductions.

Another, and perhaps the most striking, feature of Figs. 2 and 4 is the discontinuity of the relation between strength and hardness as the mode of cold working changes from drawing (10 and 25 per cent reductions) to rocking (51 and 65 per cent reduction)*. This interruption of the function is even more apparent in the ductility values, Figs. 3 and 5, which are discussed below. This continuity probably stems from the difference between the stress states imposed on the tubes during the cold working operations. The drawing process induces stresses which are primarily tensile, while the Rockrite process produces primarily compressive stresses. It is thought by many engineers, and there appears to be supporting evidence, that compressive deformation processes are less effective in increasing hardness (and also in reducing ductility) than tensile working processes. The results of the study reported here appear to confirm this belief.

Cold work affected the conventional tensile ductility, Figs. 3 and 5, in a manner similar to the way it affected the strength properties, except, of course, the ductility was reduced by cold work. These similarities are: the linearity between the change in ductility with increasing cold work for the drawn reductions; the small effect of stress relieving at these low reductions; the common ductility values for both steels in the low reductions and in the normalized condition; and the discontinuity (as a function of amount of cold work) when the mode of cold working changed from drawing to rocking.

The ductility values for both steels appear to be relatively independent of the amount of cold work in the range 51 to 65 per cent reduction in area

- - - -

* This discontinuity was also noted in the residual stress content of the tubes as a function of cold reduction, Tech. Report No. 12, WAL Report No. 310/90-51.

for cold finishing accomplished by the Rockrite process. Furthermore, the ductility values for tubes with these two high reductions were the same as, and in a few cases actually greater than, the ductility values for drawn tubes with a much less amount of cold work (25 per cent). Such an increase in ductility would not be common behavior for a material undergoing increasing amounts of cold work through the same mechanism. For the rocked tubes, the stress relieving treatment caused an increase in ductility for both steels.

It is interesting to note that the contraction in area values for both steels after 65 per cent cold reduction was still 50 to 60 per cent, a decrease of only approximately 10 per cent from the normalized values. This would seem to indicate that substantially greater amounts of cold work could have been put into the tubes without causing rupture during fabrication.

Notched Tensile Tests

The results of the notched bar tensile tests are listed in Tables III and IV and are represented graphically in Figs. 6 to 9.

In this portion of the testing, two different notch radii were employed. The sharp notch (0.0005 inch root radius, notch sharpness* of 212) was designed to induce both a multiaxial stress state and a stress raiser. The stress state in this case has been shown to be both biaxial and triaxial, with the former being the more severe. The milder notch (0.032 inch root radius, notch sharpness of 33) induces a primarily triaxial stress state, with a very low stress raising effect.

The notch strength, when plotted as a function of the amount of cold work, Figs. 6 and 7, shows effects similar to those of the regular tensile strength (values for which have been added to the figures for comparison purposes). This is especially true for the 1040 drawn tubes, Fig. 6. As had been noted in previous results, stress relieving treatment showed little effect on notch strength. In these representations, it is again evident that the change in the mode of cold work from drawing to rocking destroys the continuity of the dependence of the notch properties on the amount of cold work.

- - -

* Notch sharpness is here defined as the dimensionless ratio of one-half the root diameter to the notch radius.

In evaluating static notch tensile test data, it is often convenient to represent the test results as a function of conventional tensile strength (strength level). Illustrations of this type permit direct observations of notch sensitivity. Generally speaking, the introduction of a multiaxial stress state, through the medium of a notch in this case , tends to produce a strengthening of the material since the lateral tensions increase the longitudinal tension required to bring about a certain strain. If the notch does not embrittle the material at the same time that it increases the effective flow stress, this strengthening effect is dependent primarily upon the geometrical configuration. Furthermore, relative magnitude of the strengthening effect for a given notch geometry in an unembrittled material is independent of the tensile strength, i.e., the ratio between notch strength and tensile (notch strength ratio) is constant.

On the other hand, if the notch does produce an embrittlement, the notch strength ratio will be less than that predicted for a ductile behavior. Consequently, a representation of the notch tensile properties as a function of strength level provides a means for showing the notch sensitivity directly.

Figs. 8 and 9 show the notch tensile data as a function of strength level* for both conditions of each steel. For the notch geometry used in the tests, previous work on both heat treated and cold worked steels showed empirically that the notch strength for a ductile behavior (notch insensitivity) should be approximately 50 per cent greater than the tensile strength (notch strength ratio equals 1.5). A line representing notch strength of 1.5 times the tensile strength has been constructed on these figures. It can be seen readily that the data fall near to (or above but parallel to) this constructed line. This indicates that both steels are not sensitive to the notches used in this study.

The notch ductilities, also plotted on Figs. 8 and 9 are all relatively high, the lowest of any reported value being 5.4 per cent (for the stress relieved condition of the 1040 steel with 25 per cent reduction). It has been found previously that the inception of notch sensitivity takes place when the

- - - - -

* The strength levels for a given treatment on each steel are the conventional tensile strengths for the same condition, Table I.

notch ductility values are lowered to values of 2 or 3 per cent. The embrittlement then increases as the notch ductility decreases to values lower than this. It is interesting to note that the lowest notch ductility found was that for the tube with the largest drawn reduction. Rocked tubes with even greater reductions possessed greater notch ductility. This again seems to point to the smaller damaging effect of the rocking process (compared with the drawing process).

Generally speaking, the notch strength of tubes of both steels at all reductions was higher in the presence of the sharper notch than it was in the presence of the milder notch; in addition, the ductility was lower. Stress relieving appeared to have little effect upon the notch properties of either steel for any reduction, probably because the inherent ductility was reasonably large even in the presence of these embrittling agents.

All the notch data for the 1040 steel tubes appear to follow the 1.5 notch atrength ratio relation fairly well. However, the data from sharply notched specimens from the 8630 steel tubes seem to follow a 1.8 notch strength ratio relation. No explanation is immediately apparent for this behavior.

The discontinuity between the two methods of deformation, noted for previous mechanical properties, is not apparent for the representation of notch strength as a function of strength level. This is to be expected because, for a given type of material (if the specimens are notch insensitive), the notch strength is chiefly a function of notch geometry and absolute strength, and little dependent on the manner in which a given strength level is achieved. It would be expected, also, that the differences between drawing and rocking would become apparent if greater amounts of cold work were used. With these greater amounts of cold work, indications are that the drawn tubes would lose ductility more quickly than the rocked tubes, and thus begin to show notch sensitivity more rapidly.

CONCLUSIONS

For the results of the study reported herein, the following conclusions may be drawn.

Cold drawing up to 25 per cent reduction increased the conventional tensile and yield strengths and decreases the tensile ductility of AISI 1040 and 8630 steel tubes almost linearly with the amount of cold work. Cold work introduced by the Rockrite process in amounts between 51 and 65 per cent again increased the conventional tensile and yield strengths of these tubes almost linearly, but had little effect on reducing the tensile ductility. Furthermore, as the mode of cold work changed from drawing to rocking, the continuity of the function relating tensile and yield strengths with amount of cold work was destroyed.

The test results indicate that for equivalent amounts of cold work, the Rockrite process would be less effective than the drawing process in strengthening the steel tubes. At the same time indications are that the Rockrite process would be less damaging to the tensile ductility of the steel tubes than the drawing process for the same amount of cold work.

Thermal stress relieving had little effect on the tensile properties of drawn tubes of either steel. However, it decreased the tensile and yield strengths and increased the ductility of rocked tubes.

Static notch tensile tests indicated that tubes of both steels at all reductions and in both the stress relieved and the aged conditions were insensitive to the stress raisers and multiaxial stress states induced by the notch geometries employed. However, it appeared that tubes cold worked by the Rockrite process would retain more notch ductility than those cold drawn if comparable reductions were studied.

The data gathered in this study indicated that amounts of cold work considerably in excess of 65 per cent reduction in area, could be induced into tubes of both steels by the Rockrite process. It appears further that this added cold work might raise the tensile strength attainable considerably over the maximum of approximately 125,000 psi reached in this study for both steels without depleting the tensile ductility inordinately, and without causing the tubes to become notch sensitive (on the basis of the static concentric notch tensile test).

TABLE I

THE EFFECT OF COLD WORK ON THE CONVENTIONAL
TENSILE PROPERTIES OF NORMALIZED AISI 1040 STEEL TUBE
0.212 INCH DIAMETER SPECIMEN

Per Cent Reduction	Condition	Tensile Strength 1000 Psi	0.2% Yield Strength 1000 Psi	Contraction in Area Per Cent	Elongation Per Cent
0	Normalized	84.0	50.1	60.6	34.1
"	"	83.9	50.7	64.7	34.1
"	"	83.1	49.7	65.4	32.9
10	Aged	93.0	-	57.0	23.5
"	"	92.9	80.5	58.5	20.0
"	"	92.6	81.9	57.5	20.5
25	Aged	109.3	101.7	49.3	14.1
"	"	108.3	98.3	49.4	14.1
"	"	109.7	100.3	49.9	14.1
51	Aged	115.7	110.3	50.2	14.1
"	"	114.4	107.5	52.7	15.2
"	"	113.5	104.2	51.3	15.2
65	Aged	125.6	113.4	49.4	12.9
"	"	129.0	-	49.2	15.2
"	"	126.4	118.4	49.7	12.9
10	Stress Rel.	95.5	73.8	56.1	22.3
"	"	95.4	74.1	-	22.3
"	"	93.8	-	57.3	22.3
25	Stress.Rel.	108.5	91.2	51.0	17.6
"	"	110.2	91.5	49.6	17.6
51	Stress Rel.	108.1	96.8	54.6	20.0
"	"	111.4	99.2	52.3	18.8
"	"	111.4	99.7	52.7	22.3
65	Stress Rel.	119.5	113.2	53.6	20.0
"	"	116.5	109.6	53.3	20.0
"	"	118.8	111.0	55.8	18.8

TABLE II

THE EFFECT OF COLD WORK ON THE CONVENTIONAL
TENSILE PROPERTIES OF NORMALIZED AISI 8630 STEEL TUBE 0.212 INCH
DIAMETER SPECIMENS

Per Cent Reduction	Condition	Tensile Strength 1000 Psi	0.2% Yield Strength 1000 Psi	Contraction in Area Per Cent	Elongation Per Cent
0	Normalized	85.3	56.0	67.0	33.5
"	"	85.7	56.0	67.3	37.0
"	"	83.1	54.9	69.6	35.2
10	Aged	93.6	77.9	66.5	29.4
"	"	94.0	77.6	65.9	23.5
"	"	94.6	-	57.4	24.7
25	Aged	109.5	100.4	58.9	16.5
"	"	109.9	96.9	57.9	16.5
"	"	110.0	-	59.2	17.1
51	Aged	114.0	107.2	60.9	18.8
"	"	116.1	112.7	60.3	17.6
"	"	117.0	110.4	59.8	17.6
65	Aged	125.1	117.5	57.2	15.3
"	"	127.2	121.2	61.1	16.5
"	"	126.1	-	57.9	16.5
10	Stress Rel.	98.3	79.3	64.9	24.7
"	"	98.4	80.3	64.6	22.3
"	"	99.6	81.6	64.6	24.7
25	Stress Rel.	114.0	98.7	57.8	18.8
"	"	114.6	-	57.1	20.0
"	"	113.3	98.8	57.2	20.0
51	Stress Rel.	111.8	100.7	61.9	24.7
"	"	113.0	100.6	60.6	23.5
"	"	114.0	102.4	60.9	23.5
65	Stress Rel.	119.0	110.9	60.2	20.5
"	"	119.7	110.3	57.9	20.0
"	"	118.1	110.3	59.7	20.5

TABLE III

THE EFFECT OF COLD WORK ON THE STATIC NOTCH TENSILE PROPERTIES OF NORMALIZED AISI 1040 STEEL TUBE

Per Cent Reduction	Condition	Notch Radius Inch	Notch Strength 1000 Psi	Notch Ductility % Contraction in Area
10	Aged	.0005	158.0	8.7
"	"	"	158.0	9.9
25	"	"	167.0	3.5
"	"	"	164.1	7.6
"	"	"	168.5	6.8
51	"	"	181.5	13.8
"	"	"	180.2	11.3
65	"	"	205.5	7.6
"	"	"	205.0	6.8
"	"	"	202.0	6.9
10	Stress Rel.	"	174.5	7.7
"	"	"	153.5	9.0
"	"	"	154.7	9.5
25	"	"	-	-
"	"	"	167.5	5.1
"	"	"	164.8	5.6
51	"	"	177.8	13.2
"	"	"	173.5	14.3
"	"	"	175.0	13.8
65	"	"	197.5	7.2
"	"	"	192.9	7.7
"	"	"	196.0	8.0
10	Aged	.032	138.3	25.6
"	"	"	139.8	26.9
"	"	"	139.1	24.4
25	"	"	165.1	17.8
"	"	"	164.6	20.5
"	"	"	163.8	21.4
51	"	"	168.5	11.8
"	"	"	171.3	14.7
"	"	"	172.6	15.0

TABLE III (Cont'd)

Per Cent Reduction	Condition	Notch Radius Inch	Notch Strength 1000 Psi	Notch Ductility % Contraction In Area
65	Aged	.032	183.2	13.0
"	"	"	188.3	12.5
"	"	"	183.1	14.1
10	Stress Rel.	"	137.3	25.3
"	"	"	137.6	25.1
"	"	"	137.6	26.4
25	"	"	160.5	19.0
"	"	"	160.6	18.8
"	"	"	158.9	18.3
51	"	"	162.4	19.6
"	"	"	162.6	19.3
"	"	"	161.0	18.7
65	"	"	172.5	19.6
"	"	"	174.1	16.4
"	"	"	169.8	19.7

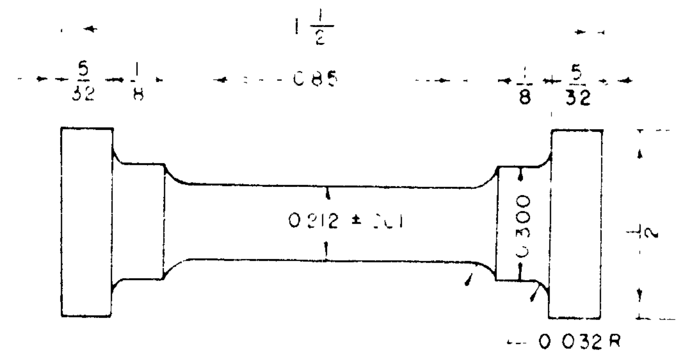
TABLE IV

THE EFFECT OF COLD WORK ON THE STATIC NOTCH TENSILE PROPERTIES OF NORMALIZED AISI 8630 STEEL TUBE

Per Cent Reduction	Condition	Notch Radius Inch	Notch Strength 1000 Psi	Notch Ductility % Contraction In Area
10	Aged	.0005	178.0	14.3
"	"	"	175.0	14.1
"	"	"	176.5	14.1
25	"	"	199.2	13.4
"	"	"	200.5	13.4
"	"	"	204.0	14.6
51	"	"	208.0	15.7
"	"	"	210.0	15.8
"	"	"	210.1	15.4
65	"	"	227.0	13.5
"	"	"	216.0	10.5
"	"	"	222.5	12.8
10	Str. Rel.	"	168.5	12.8
"	"	"	166.5	13.0
"	"	"	169.0	14.3
25	"	"	203.0	17.3
"	"	"	178.5	17.3
"	"	"	197.5	15.4
51	"	"	206.1	21.4
"	"	"	205.0	17.8
"	"	"	207.5	20.0
65	"	"	214.5	15.2
"	"	"	214.0	14.7
"	"	"	211.2	14.5
10	Aged	.032	143.6	34.1
"	"	"	144.6	37.4
"	"	"	144.0	35.9
25	"	"	168.4	29.9
"	"	"	166.7	27.0
"	"	"	172.8	26.2
51	"	"	176.9	30.7
"	"	"	171.1	24.9

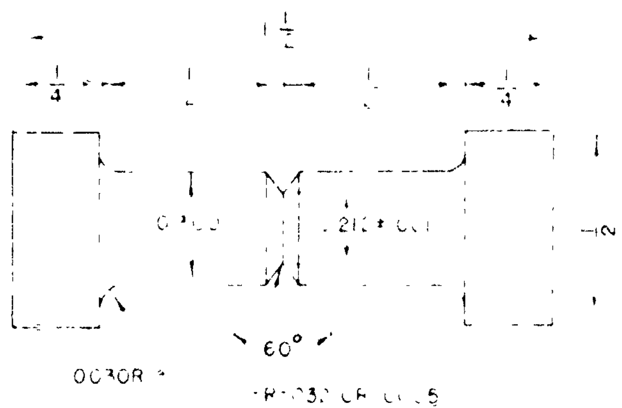
TABLE IV (Cont'd)

Per Cent Reduction	Condition	Notch Radius Inch	Notch Strength 1000 Psi	Notch Ductility % Contraction In Area
65	Aged	.032	186.9	23.1
"	"	"	183.0	20.4
"	"	"	186.6	19.6
10	Str. Rel.	"	143.9	36.8
"	"	"	141.4	36.6
"	"	"	143.9	36.2
25	"	"	166.4	22.9
"	"	"	165.7	25.7
51	"	"	160.1	25.9
"	"	"	162.4	27.3
"	"	"	163.8	27.9
65	"	"	172.9	28.1
"	"	"	175.6	25.3



* LARGEST CONVENIENT RADIUS

BUTTON HEAD TENSILE SPECIMEN



NOTCHED CONCENTRIC BUTTONHEAD
TENSILE SPECIMEN

FIG I UNNOTCHED (UPPER) AND NOTCHED (LOWER)
TENSILE TEST SPECIMENS

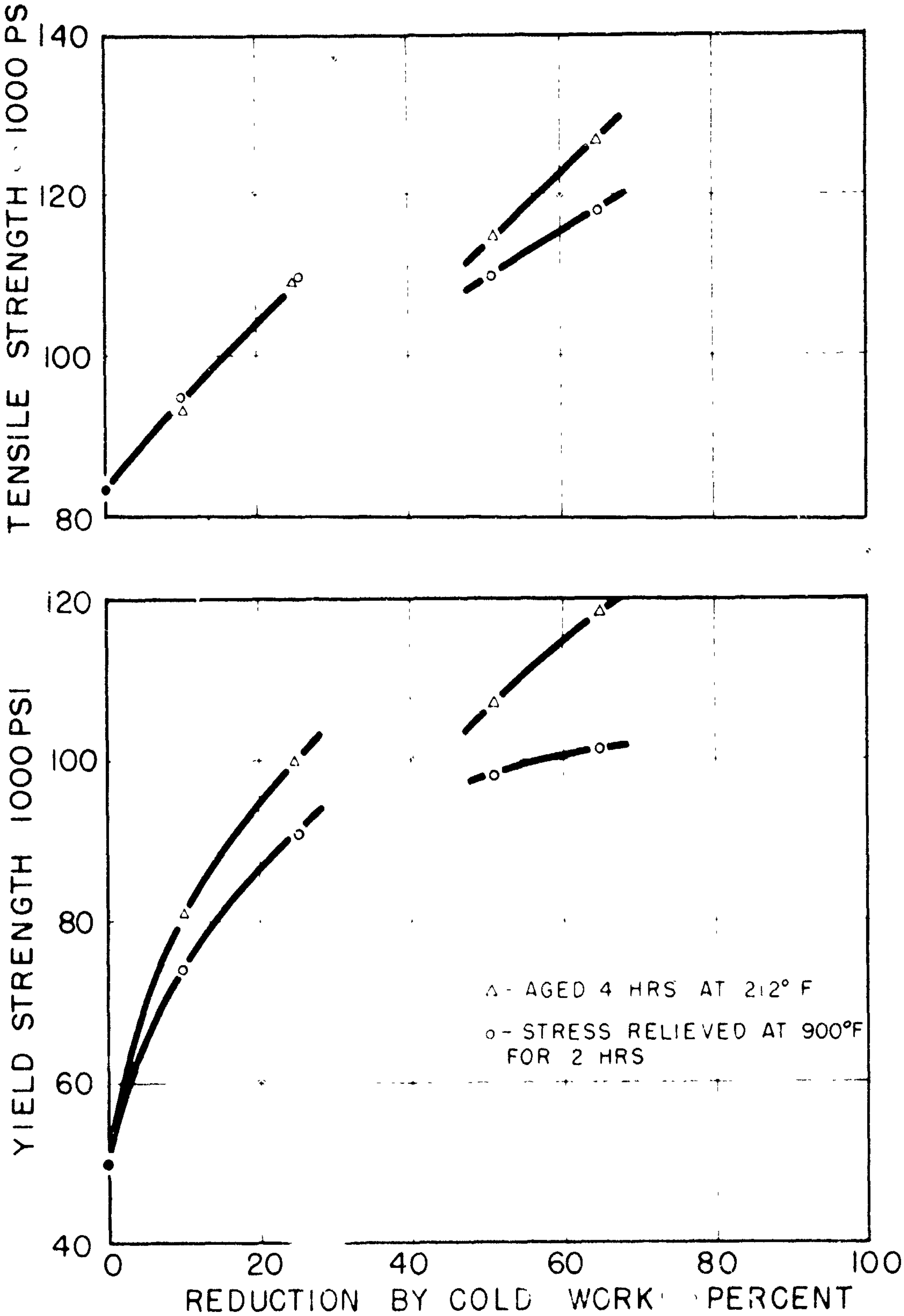


FIG 2 THE EFFECT OF COLD WORK ON THE STRENGTH PROPERTIES OF 1040 STEEL TUBES.

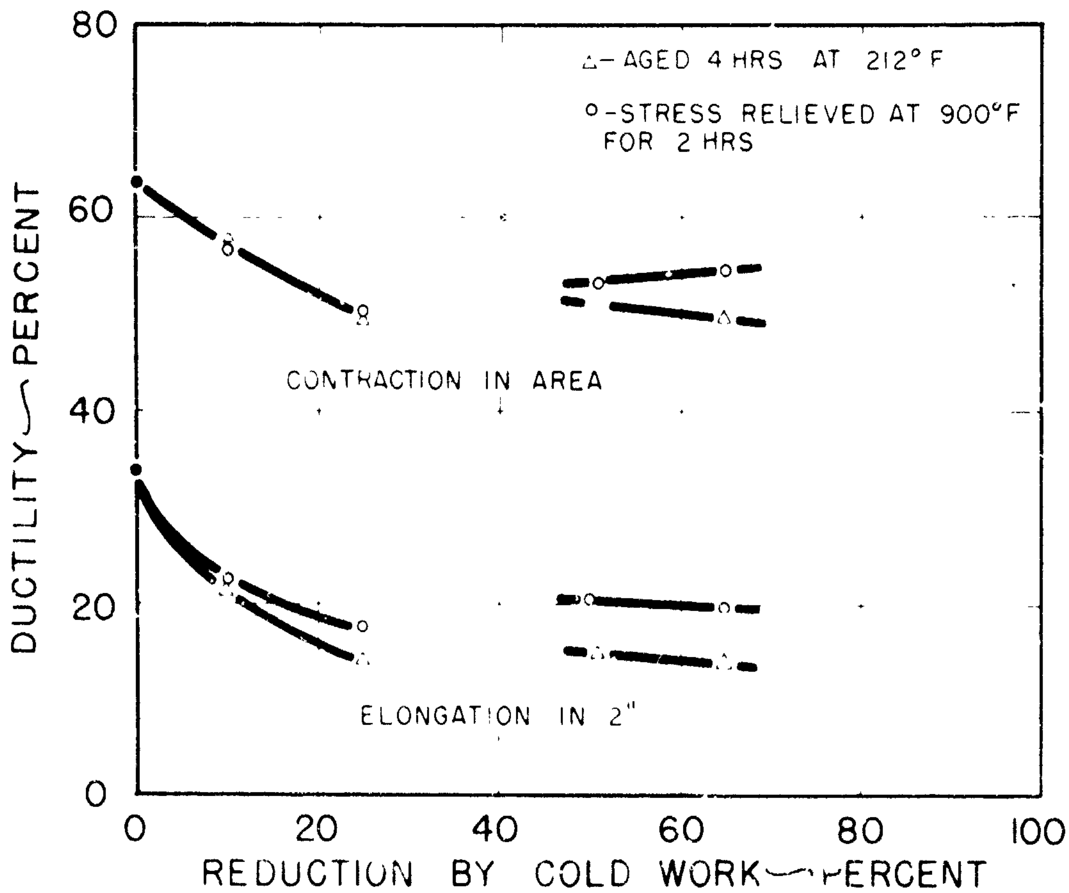


FIG 3 THE EFFECT OF COLD WORK ON THE DUCTILITY OF 1040 STEEL TUBES.

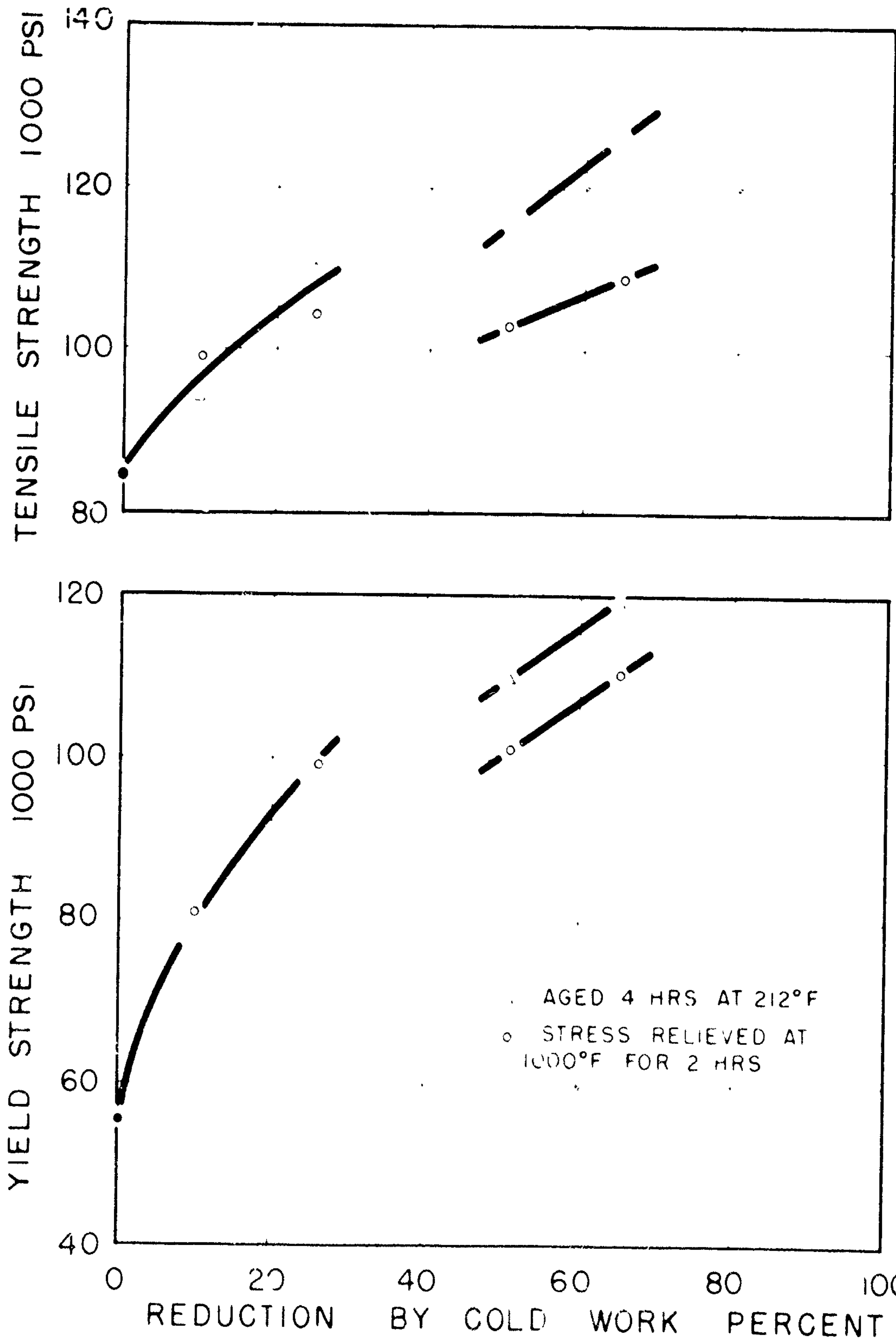


FIG 4 THE EFFECT OF COLD WORK ON THE STRENGTH PROPERTIES OF 8630 STEEL TUBES.

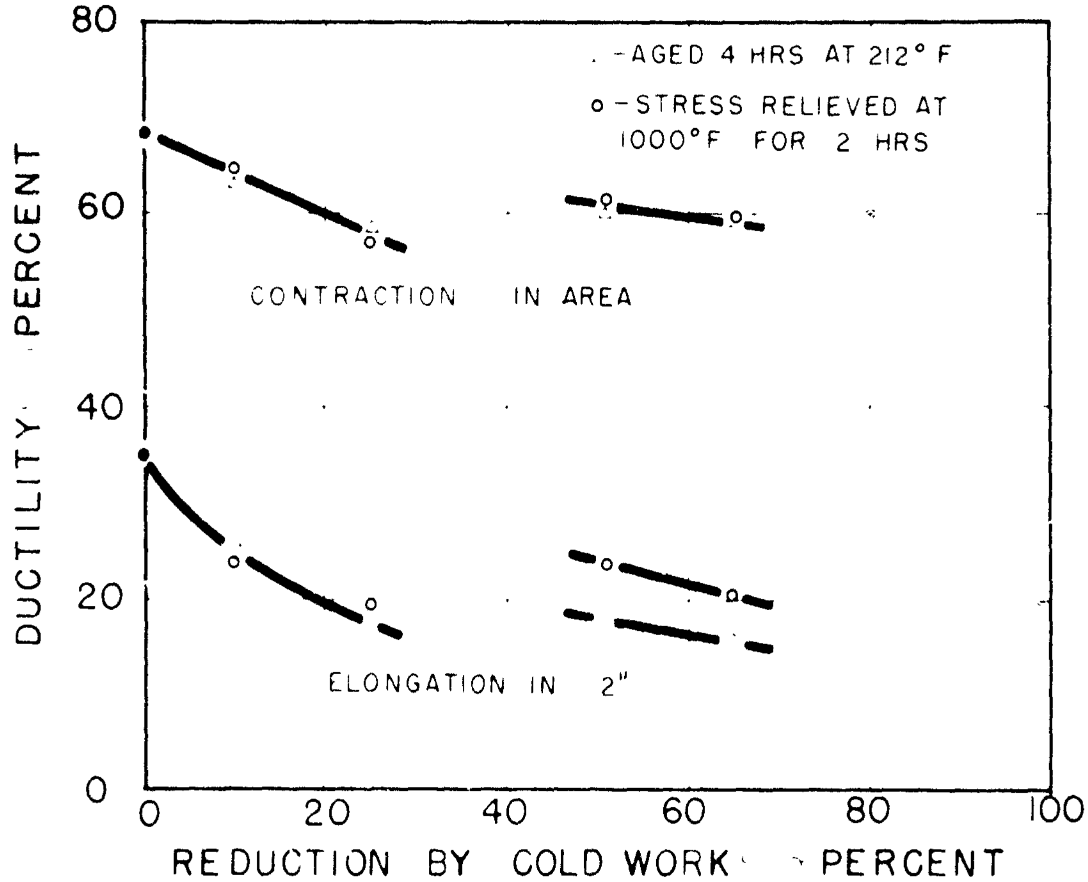


FIG 5 THE EFFECT OF COLD WORK ON THE DUCTILITY AND ELONGATION OF 8630 STEEL TUBES

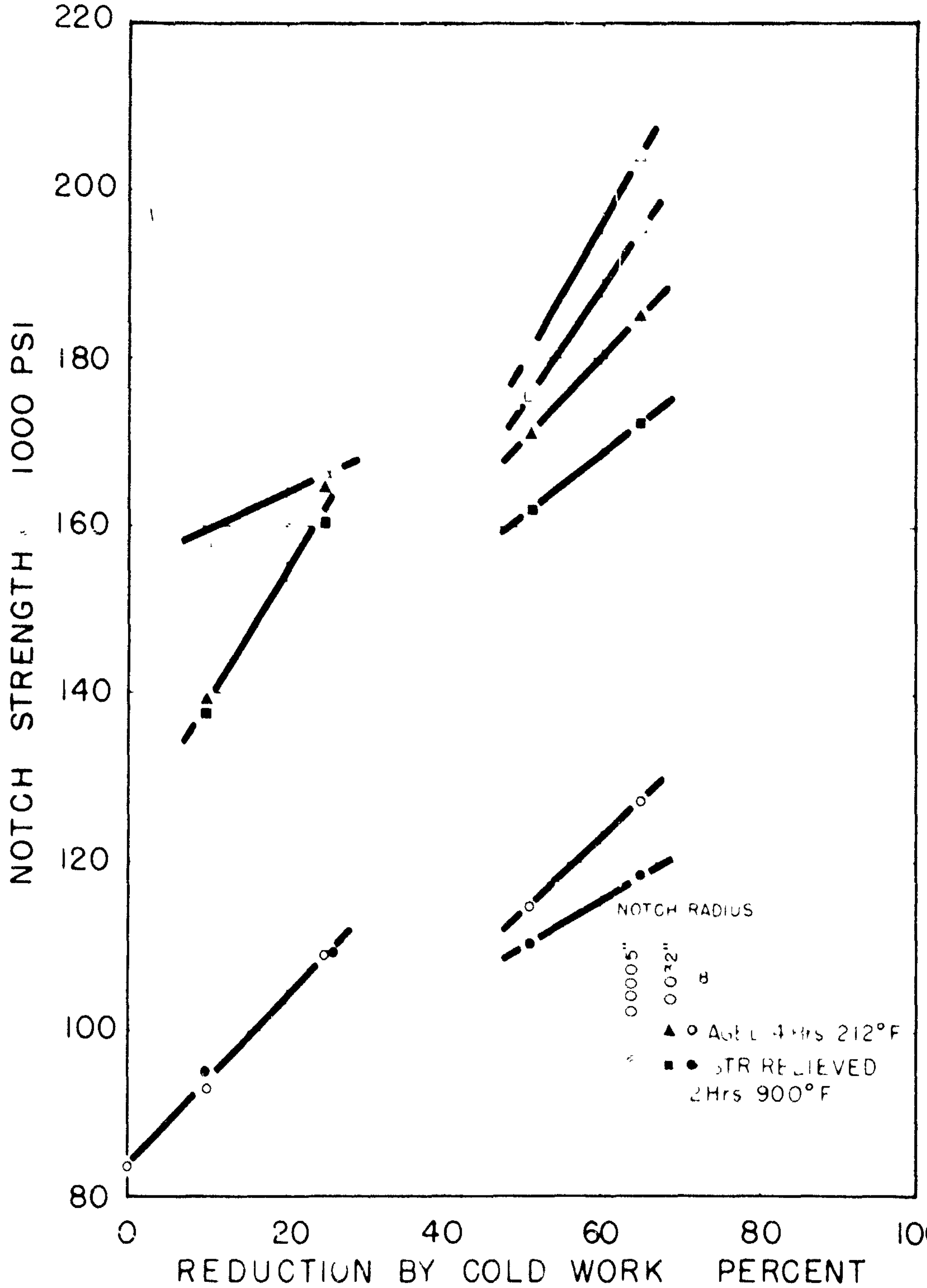


FIG. 6 EFFECT OF COLD WORK AND NOTCH RADIUS ON THE CONCENTRIC NOTCH STRENGTH OF 1040 STEEL TUBES.

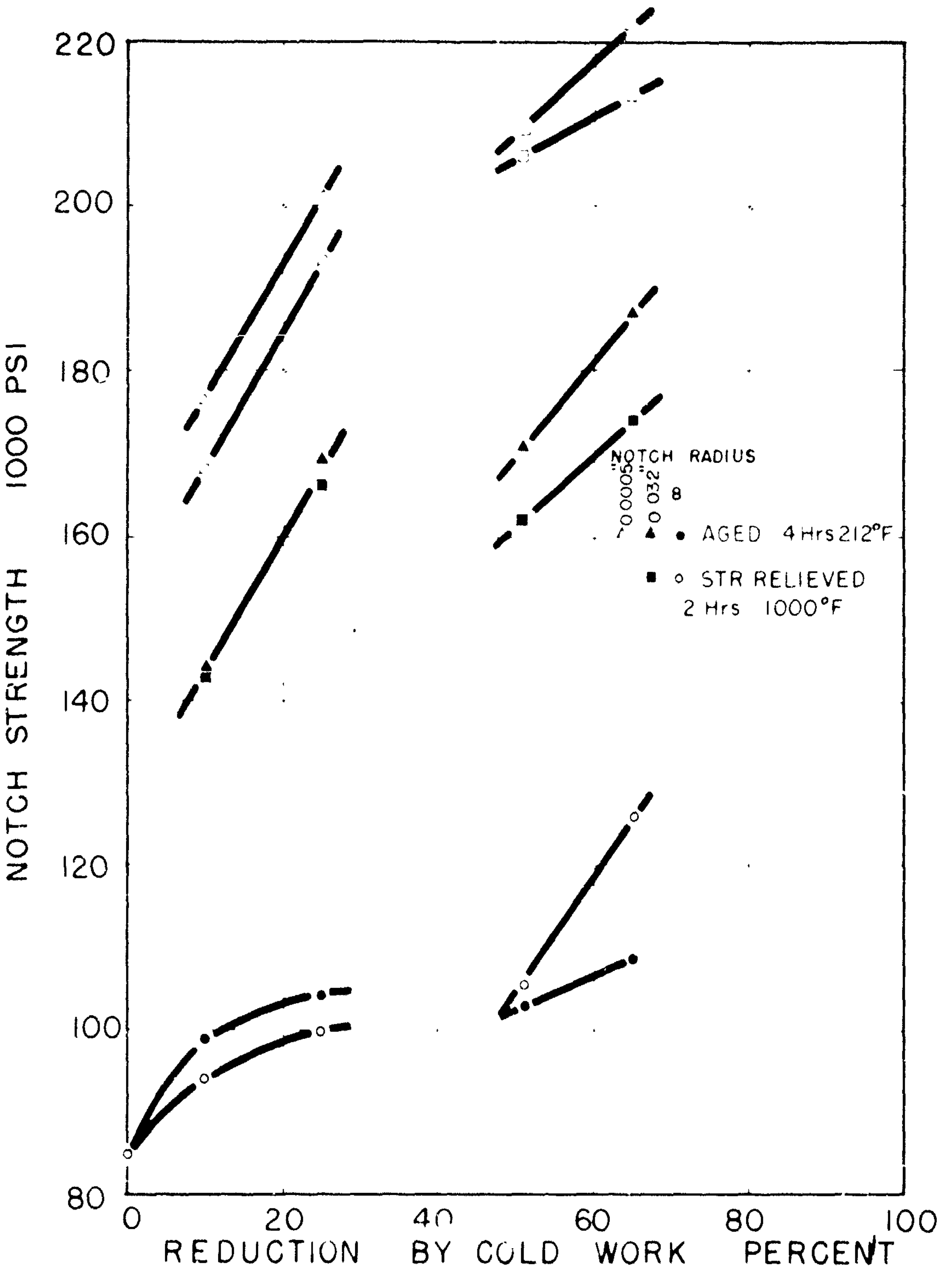


FIG 7 EFFECT OF COLD WORK AND NOTCH RADIUS ON THE CONCENTRIC NOTCH STRENGTH OF 8630 STEEL TUBES.

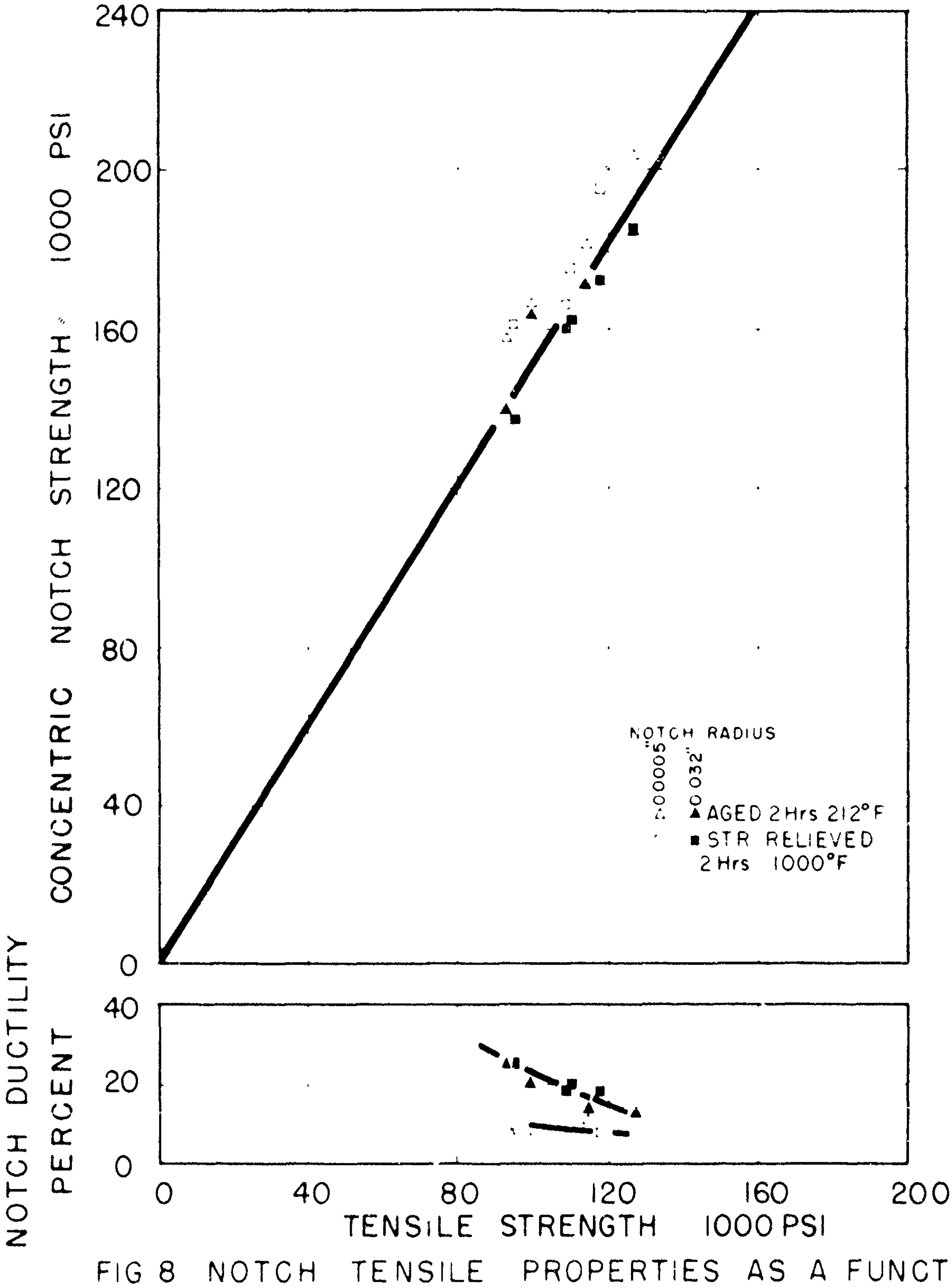


FIG 8 NOTCH TENSILE PROPERTIES AS A FUNCTION OF STRENGTH LEVEL FOR COLD WORKED 1040 STEEL TUBES

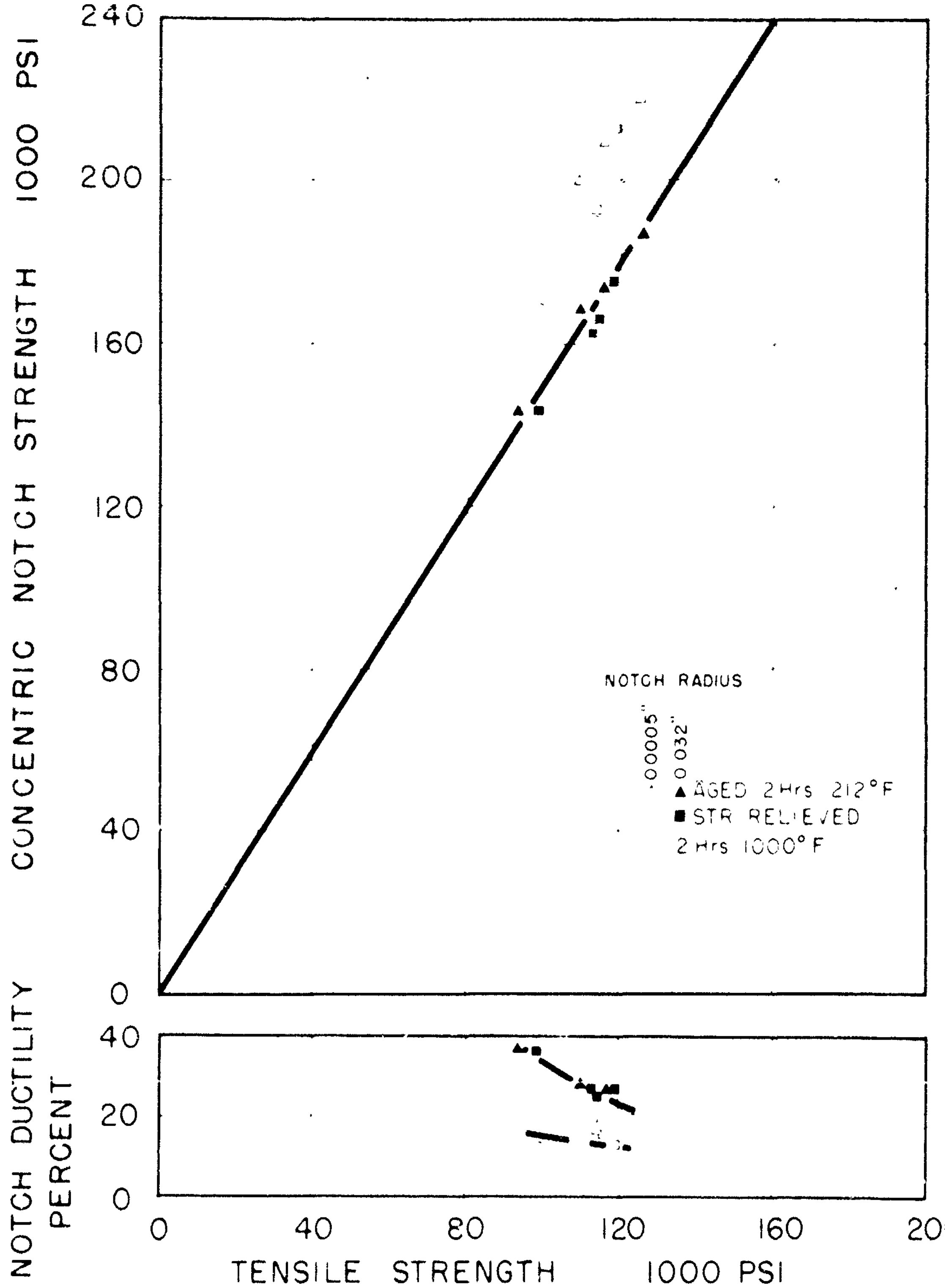


FIG 9 NOTCH TENSILE PROPERTIES AS A FUNCTION OF STRENGTH LEVEL FOR COLD WORKED 8630 STEEL TUBES

Distribution List For
Technical Report
No. 13

WAL Project No. 10.45-S
Report No. 310/90-52
Contract No. DA-33-019-ORD-7

Copy Number	
1-9	Office, Chief of Ordnance Washington D. C. Attn: ORDTB - 1 copy ORDTR - 1 copy ORDTU - 1 copy ORDTM - 1 copy ORDTX-AR - 1 copy ORDTS - 1 copy ORDII - 1 copy ORDIX - 2 copies
10	Commanding Officer Detroit Arsenal Centerline, Michigan
11	Commanding Officer Watervliet Arsenal Watervliet, New York
12	Commanding Officer Picatinny Arsenal Dover, New Jersey
13	Commanding Officer Rock Island Arsenal Rock Island, Illinois
14-15	Commanding Officer Aberdeen Proving Ground Aberdeen, Maryland
16	Commanding Officer Springfield Arsenal Springfield, Massachusetts
17-18 /	Commanding Officer Watertown Arsenal Watertown, Massachusetts
19	Commanding Officer Navy Department - Bureau of Ordnance Office of Naval Research Washington, D. C.
20	Commanding Officer Frankford Arsenal Philadelphia, Pennsylvania

21 Commanding General
Air Materiel Command
Wright-Patterson Air Force Base
Dayton, Ohio
Attn: MCREXM

22 Republic Steel Corporation
Union Drawn Steel Division
Massillon, Ohio
Att: J. D. Armour

23 Acting District Chief
Cleveland Ordnance District
Cleveland, Ohio

24 National Research Director
Committee on Ship Steel
2101 Constitution Avenue
Washington, D. C., Att: Dr. Finn Jonassen

25 Babcock & Wilcox Tube Company
Beaver Falls, Pennsylvania
Att: J. J. B. Rutherford

26 Tube Reducing Corporation
520 Main Avenue
Wallington, New Jersey
Att: J. D. Judge

27 District Chief
Pittsburgh Ordnance District
808 Ridge Avenue
Pittsburgh, Pennsylvania

28 Dr. W. M. Baldwin, Jr.
Case Institute of Technology

29 Dean Elmer Hutchisson
Case Institute of Technology

30 Professor K. H. Donaldson
Case Institute of Technology

31 Mr. L. J. Ebert
Case Institute of Technology

32 Mr. G. S. Sangdahl, Jr.
Case Institute of Technology

33 Metals Research Laboratory (File)
Case Institute of Technology